

VERITAS Observations of M 87 in 2011/2012

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Abstract.

The giant radio galaxy M 87 is located at a distance of 16.7 Mpc and harbors a super-massive black hole (6 billion solar masses) in its center. M 87 is one of just three radio galaxies known to emit TeV γ -rays. The structure of its relativistic plasma jet, which is not pointing towards our line of sight, is spatially resolved in X-ray (Chandra), optical and radio (VLA/VLBA) observations. The mechanism and location of the TeV emitting region is one of the least understood aspects of AGN. In spring 2008 and 2010, the three TeV observatories VERITAS, MAGIC and H.E.S.S. detected two major TeV flares in coordinated observations. Simultaneous high-resolution observations at other wavelengths – radio (2008) and X-rays (2008/2010) – gave evidence that one of the TeV flares was related to an event in the core region; however, no common/repeated patterns could be identified so far. VERITAS continued to monitor M 87 in 2011/2012. The results of these observations are presented.

Keywords: gamma-rays, active galactic nuclei, black hole, radio galaxy: M 87, VERITAS

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INTRODUCTION

Due to its super-massive black hole and its close proximity of 16.7 Mpc structures of the relativistic plasma jet in M 87 can be resolved in radio to X-ray observations [27]. This makes M 87 a unique AGN that potentially allows to spatially constrain the location of the TeV γ -ray emission (radio/X-ray vs. TeV flux correlation studies). Such a result would provide important input for AGN unification theories and plasma jet physics.

M 87 is now a well established TeV γ -ray source [1, 2, 3, 4] with observed TeV flux variability on time scales of days [3, 5, 6]. The variability strongly constrains the size of the emission region to the order of ten Schwarzschild radii. This rules out interpretations related to large scale emission from dark matter annihilation in M 87 [7] or cosmic ray interaction [8]. Leptonic [9, 10, 11] and hadronic [12] jet emission models are discussed in the literature as well as different potential locations of the TeV γ -ray emission: the nucleus [13], the inner jet [9, 12] or the (large scale) jet [14, 15, 16].

Since 2007 TeV γ -ray observations of M 87 have been closely coordinated between VERITAS, MAGIC, and H.E.S.S. This drastically improved the chances of detecting active flux states and substantially increased the scientific outcome of the observations. Target-of-opportunity (ToO) observations were proposed at radio (VLBA) to X-ray (Chandra) energies. So far, three TeV γ -ray flares have been detected in the past 13 years of M 87 observations:

2005: H.E.S.S. observations in 2004/2005 confirmed M 87 as a TeV γ -ray source. Surprisingly, flux variability was found on time scales of days [3]. The year 2005 also marked the maximum of an radio/optical/X-ray high state of the innermost knot in the

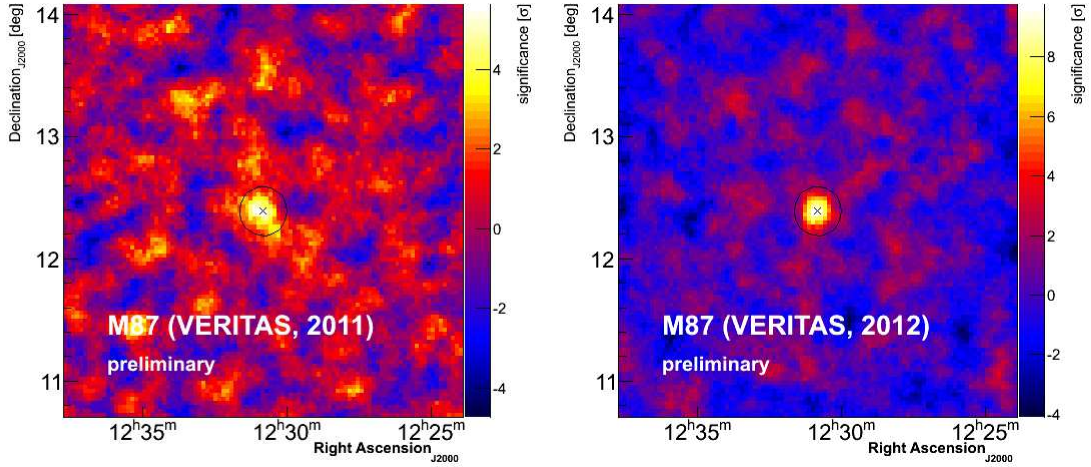


FIGURE 1. M87 sky maps (smoothed excess significances, ring background) measured by VERITAS in 2011 (left) and 2012 (right).

jet, HST-1, located roughly 60 pc away from the core [17]. Since this high state lasted for almost one year – with correspondingly slow time scales of flux changes – it is not clear whether it was related to the TeV flare.

2008: A strong TeV γ -ray flare was detected in joint VERITAS, MAGIC, and H.E.S.S. observations in 2008 confirming the day-scale flux variability [18, 3, 5]. The flare marked the onset of a rise in the 43 GHz radio flux (VLBA) from the nucleus. The VLBA observations resolve the nucleus with very high precision of 30×60 Schwarzschild radii; the radio nucleus is believed to be coincident with the black hole position [19]. Combining the radio and TeV data therefore gave first experimental evidence that the TeV emission actually originates from the close vicinity of the black hole [6].

2010: The strongest TeV γ -ray flare so far was detected by VERITAS and MAGIC in 2010 (Fig. 3, left), also triggering follow-up observations by H.E.S.S. [20, 21]. Radio, optical, and X-ray observations were triggered in addition to the accompanying Fermi/LAT observations of the source. Although the flux of the radio nucleus remained at the base level the weeks following the TeV flare – not confirming the 2008 finding – two interesting observations were made in the contemporaneous multi-wavelengths (MWL) monitoring: (i) the Chandra observations (starting ~ 4 d after the peak of the TeV flare) showed the second highest flux measured from the nucleus so far [23] (Fig. 3, left); (ii) a new radio feature was identified in the knot HST-1 following the flare [22].

VERITAS OBSERVATIONS OF M 87 IN 2011/2012

VERITAS continued monitoring M 87 in 2011/2012. The observations were coordinated with MAGIC, H.E.S.S., and the MWL partners of the previous campaigns. A total of 17 hrs of good quality data were accumulated by VERITAS in 2011. Only a weak signal at the level of 5 std. dev. was detected, see Fig. 1, left. The 2012 observations resulted in a total of 29 hrs of data. M 87 is detected at the level of 9 std. dev., see Fig. 1, right.

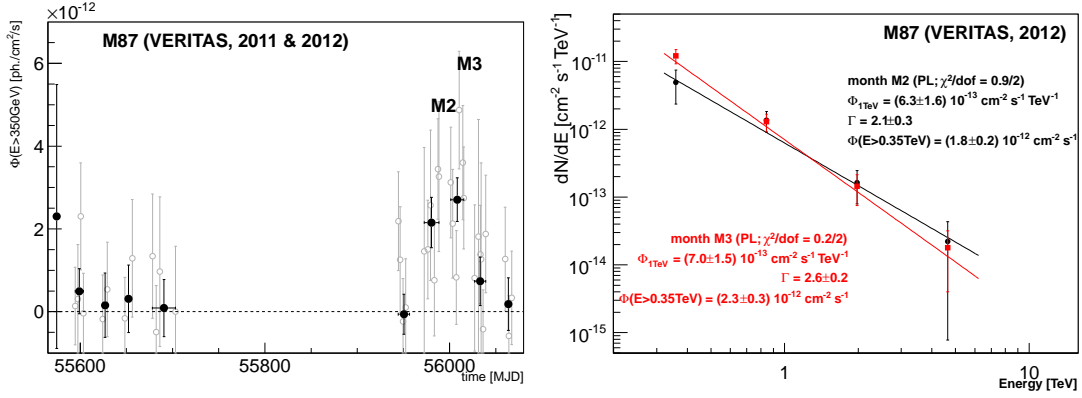


FIGURE 2. **Left:** VERITAS light curve of M87 in 2011/2012 (gray: nightly fluxes; black: monthly fluxes). Elevated flux levels were measured in 2012 during the months M2 and M3. **Right:** Energy spectra derived for data sets M2 and M3. The spectra were fitted by power laws.

The light curve of the two years is shown in Fig. 2, left, and indicates variability on time scales of weeks (but not days) in 2012: two months (M2 and M3) with clearly elevated flux are identified. The energy spectra derived for these two months are shown in Fig. 2, right, and are found to be compatible with each other. Figure 3 shows the photon index Γ vs. the TeV flux normalization of these spectra as well as for archival data. Nightly flux levels that would allow to trigger the MWL observations were not reached in 2011/2012.

SUMMARY AND CONCLUSION

M87 was monitored by VERITAS in 2011/12 for 36hrs in coordination with MAGIC and H.E.S.S. While the VERITAS data of 2011 and 2012 did not show bright flares, the monthly variation in TeV flux hint that the underlying quiescent emission also evolves over much longer time scales than the day-scale rapid flares seen in 2008 and 2010. This makes long term monitoring of M87 in TeV and other wavebands scientifically very fruitful.

Although promising indications were found in TeV/MWL observation of previous years the location and mechanisms of the TeV γ -ray emission are still uncertain. However, due to its proximity and jet viewing angle, M87 remains a unique laboratory to study the connection between jet formation physics and TeV γ -ray emission [24, 25, 26]. Coordinated TeV γ -ray observations accompanied by contemporaneous observations at radio (high-resolution), X-ray and Fermi energies remain one of the most promising approach to unravel the location and mechanism of TeV γ -ray emission in AGN.

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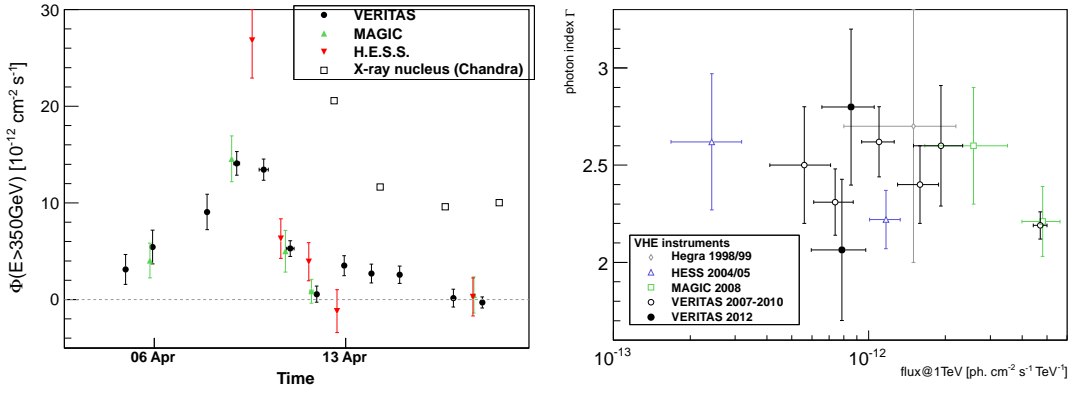


FIGURE 3. **Left:** The night-by-night light curve of the 2010 TeV γ -ray flare (VERITAS, MAGIC and H.E.S.S.; data taken from [21]). Also shown is the Chandra X-ray light curve (arbitrary units) taken from [23]. **Right:** TeV flux normalization vs. photon index Γ . A spectral hardening for high fluxes is not yet significant. Data are taken from [1, 3, 4, 5, 18] as well as the data set presented in this paper.

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